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Progress Report #3

Coupled Research in Ocean Acoustics and Signal Processing for the Next Generation of Underwater Acoustic Communication Systems

Principal Investigator's Name:	Dr. James Preisig
Period Covered By Report:	10/20/2014 to 1/19/2015
Report Date:	3/18/2015
Contract Number:	N00014-14-C-0230
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Costs Incurred This Period:	$37,351
Costs Incurred To Date:	$85,671
Estimated Costs To Complete:	$510,060

1. **Description:** Technical work this period focused on two areas. The first was continuation of work on developing a methodology within the framework of asymptotic random matrix theory (RMT) to explicitly model the time variability of acoustic channels and using this to predict underwater acoustic communications systems performance. Prior methods have accommodated time variability by assuming that the channel is time invariant over an appropriately short interval of time. By explicitly modeling the time variability within the RMT framework it is hoped that the resulting analysis will more accurately predict the trade-offs associated with the rate of channel fluctuations, the number and configuration of hydrophone array elements, the size of filters in subsequent equalizers, and the structure of the equalizer adaptation algorithms. The work has progressed with the development of a framework in which the channel variability represented by the Delay-Doppler spread function denoted by $U(\epsilon, \nu)$. For a linear channel with input $z(t)$ and output $x(t)$, the input-output relationship of the channel as represented by $U(\epsilon, \nu)$ is given by

$$x(t) \,=\, \sum_{\epsilon} z(t-\epsilon) \int U(\epsilon, \nu)\, e^{j2\pi\nu t} \mathrm{d}\nu.$$

For a particular relationship of the channel, the framework characterizes the ensemble correlation of the channel output as functions of the products of $U(\epsilon, \nu)$ parameterized by the variable α as

$$\alpha^2(\delta_\epsilon, \nu_1, \nu_2) \,=\, \sum_{\epsilon} U(\epsilon, \nu_1)\, U^*(\epsilon + \delta_\epsilon, \nu_2).$$

While assumptions regarding the statistics such as wide sense stationarity and uncorrelated scattering of different channel delay "taps" would greatly simplify the resulting expressions, the focus now is on deriving expressions conditioned on the channel realization. Analytical evaluation of the resulting expressions is proving challenging so numerical evaluation will be the near term approach moving forward. This work falls under Research Task 1 from Section 2.2 of the Technical Approach and Justification.

During this time period, the Principle Investigator has also worked on evaluating the correlation structure of received communications signals after they have been converted to the frequency domain via Fourier Transforms. Theory holds that symbol based communications signals such as those used in underwater acoustic communications when transformed into the frequency domain should have a particular banded structure after passing through a linear and wide sense stationary channel. While data from field experiments shows a structure similar to the predicted structure, the deviation is significant enough and variable

from time to time that it warrants an in-depth analysis. Analytical expressions have been derived and are being evaluated in addition to the numerical processing and analysis of data, both simulated and that collected in field experiments. The work is lending insights that will help explain how the signal correlation structure will depend on either the non-linearity or non-stationarity of the channel fluctuation and guide both algorithm design and performance prediction algorithms for underwater acoustic communication systems. This work falls under Research Task 3 from Section 2.2 of the Technical Approach and Justification.

During this time period, the Principle Investigator also wrote, revised, and/or submitted two papers based upon current and past work and helped prepare one talk for the meeting of the Acoustical Society of America meeting in Indianapolis, Indiana.

2. **Major Accomplishments this Period:** None

3. **Results and Recommendations:** None

4. **Publications and Presentations:**

B. Tomasi, D. Munaretto, J. Preisig, M. Zorzi, "Redundancy allocation in time-varying channels with long propagation delays", accepted for publication in *Elsevier Journal on Ad-hoc Networks*.

A. Yellepeddi, J. Preisig, "Adaptive Equalization in a Turbo Loop", revised and resubmitted to *IEEE Trans. on Wireless Communication*.

M. Pajovic, J. Preisig, "Performance Analytics and Optimal Design of Multichannel Equalizers for Underwater Acoustic Communications", submitted to *IEEE Journal of Oceanic Engineering*.

A. Yellepeddi, J. Preisig, "Representing the Structure of Underwater Acoustic Communication Data Using Probabilistic Graphical Models", at *168th Meeting of the Acoustical Society of America*. Indianapolis, IN, Oct. 27 - 31, 2014